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(54) Method and apparatus for removing air from an ink-jet print cartridge

(57) Method and apparatus for removing air from an ink-jet print cartridge by collecting the air in a predetermined area and drawing off the air from the air collection area using a conduit.

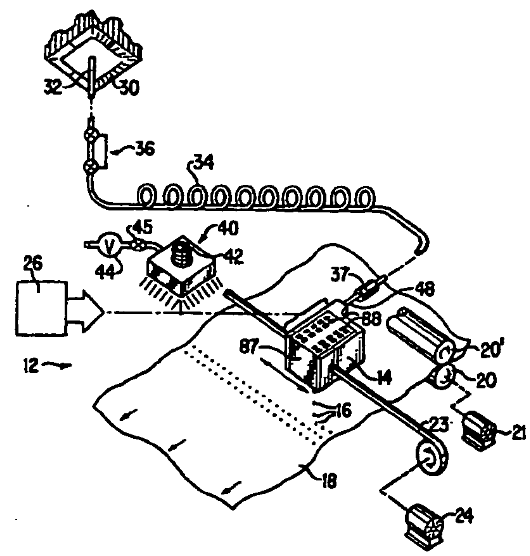

FIG. 1

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Description

The present invention relates generally to the field of ink-jet printing and, more particularly, to the delivery of ink to ink-jet print heads.

Ink-jet technology is relatively well developed. The basics of this technology are described by W.J. Lloyd and H.T. Taub in "Ink-Jet Devices," Chapter 13 of *Output Hardcopy Devices* (Ed. R.C. Durbeck and S. Sherr, Academic Press, San Diego, 1988) and in various articles in the *Hewlett-Packard Journal*, Vol. 36, No. 5 (May 1985), Vol. 39, No. 4 (August 1988), Vol. 39, No 5. (October 1988), Vol. 43, No. 4, (August 1992), Vol. 43, No.6 (December 1992) and Vol. 45. No. 1 (February 1994).

The typical thermal ink-jet print head has an array of precisely formed nozzles attached to a print head substrate that incorporates an array of firing chambers that receive liquid ink (i.e., colorants dissolved or dispersed in a solvent) from an ink reservoir. Each chamber has a thin-film resistor, known as a "firing resistor", located opposite the nozzle so ink can collect between it and the nozzle. When electric printing pulses heat the thermal ink-jet firing resistor, a small portion of the ink near it vaporizes and ejects a drop of ink from the print head. The nozzles are arranged in a matrix array. Properly sequencing the operation of each nozzle causes characters or images to form on the paper as the print head moves past the paper.

Air that is trapped in print cartridges has become an increasingly troublesome problem. In the past the accumulation of air in print cartridges was mainly ignored because the cartridges were large and could easily warehouse the air and because the cartridges had short operating lives and significant amounts of air did not accumulate. However, in today's advanced print cartridge designs the passage ways, particle filters, orifices, and conduits have become smaller and smaller. With these smaller dimensions air and air bubbles tend to block the flow of ink through the print cartridge and cause the nozzles not to eject ink. This leads to failure of the print cartridge and to require its premature replacement.

Air becomes entrapped in print cartridges from a plurality of sources. Initially air is present because it was not fully purged during manufacturing. Secondly, air bubbles may have been present during assembly in the ink tubes connecting the print head with the ink reservoir. After manufacture and for the life of the print cartridge, any dissolved air in the ink comes out of solution as bubbles. Further, air permeates into the print cartridge through the ink containment materials. Finally, in some circumstances air may be ingested into the print cartridge through the nozzles.

For a myriad of reasons the presence of air and air bubbles in ink-jet print cartridges which was previously ignored now dictates that air management become one of the factors influencing modern ink-jet cartridge design.

One system for removing air from an ink-jet print cartridge is described in US Patent 4,968,998 to Allen issued on November 6, 1990.

SUMMARY OF THE INVENTION

Briefly and in general terms, an apparatus according to the present invention includes a predetermined collection area for air within a print cartridge. Air is removed from this area by a conduit that draws off the air either through the print head or through a conduit in a wall of the print cartridge. A method according to the present invention includes the steps of collecting the air in a predetermined area, removing the air using the conduit, and replacing the air being removed with ink.

In another embodiment, an apparatus according to the present invention includes a first conduit in fluid communication with the air collection area and a second conduit in fluid communication with the ink flow path. The apparatus further includes means for shifting between the first and second conduits so that air from the collection area is removed from the print cartridge through the first conduit and ink is directed through the flow path in the print cartridge through the second conduit.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken into conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic, perspective view of an ink-jet printer according to the present invention.

Figure 2 is an exploded, perspective view of a portion of the print cartridge of Fig. 1.

Figure 3 is an exploded, perspective view of a second portion of the print cartridge of Fig. 1.

Figure 4 is a side elevation view, in cross section taken along lines 4 - 4 and 4' - 4' in Figs. 2 and 3 respectively, illustrating the normal operating position of the pressure regulator.

Figure 5 is a side elevation view, in cross section taken along lines 4 - 4 and 4' - 4' in Figs. 2 and 3 respectively, illustrating the opening of the orifice of the pressure regulator to allow the entry of ink into the housing of the print cartridge.

Figure 6 is a side elevation view, in cross section taken along lines 4 - 4 and 4' - 4' in Figs. 2 and 3 respectively, illustrating the accumulator accommodating changes in the volume of ink.

Figure 7 is a side elevation view, in cross section taken along lines 4 - 4 and 4' - 4' in Figs. 2 and 3 respectively, illustrating the service station drawing air down the snorkel and out of the print head.

Figure 8 is a side elevation view, in cross section taken along lines 4 - 4 and 4' - 4' in Figs. 2 and 3 respectively, illustrating the service station drawing air down

the snorkel and out of the print head as the orifice of the pressure regulator opens to allow the entry of ink into the housing of the print cartridge.

Figure 9 is a side elevation view, in cross section, of a print cartridge according to an alternative embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As shown in the drawings for the purposes of illustration, the invention is embodied in a method and apparatus for removing air from a print cartridge using a conduit in fluid communication with a predetermined collection area for air in the print cartridge.

Referring to Fig. 1, reference numeral 12 generally indicates a printer including a print cartridge 14 that ejects drops 16 of ink on command. The drops form images on a printing medium 18 such as paper. The printing medium is moved laterally with respect to the print cartridge 14 by two print rollers 20, 20' and a motor 21 that engages the printing medium. The print cartridge is moved back and forth across the printing medium by a drive belt 23 and a motor 24. The print cartridge contains a plurality of firing resistors, not shown, that are energized on command by an electrical circuit 26. The circuit sequentially energizes the firing resistors in a manner so that as the print cartridge 14 moves laterally across the paper and the paper moved by the rollers 20, 20', the drops 16 form images on the printing medium 18.

Referring to Fig. 1, ink is supplied to the print cartridge 14 from an ink reservoir 30. The ink reservoir is stationary and may be either flaccid or pressurized. The ink is supplied from the reservoir by an integral connector 32 that is removably attached to a conduit 34 by a double acting valve 36. The connector 32 allows the reservoir to be replaced when the ink supply is exhausted. The ink in the reservoir is maintained at a pressure sufficient to maintain the flow of ink through the conduit 34 necessary to meet the maximum ink flow requirements of the print cartridge (which could be from -20 inches to +100 inches of water). This pressure also depends on the diameter and length of the conduit 34. The conduit has a generally helical shape to accommodate the motion of the print cartridge 14 with respect to the ink reservoir 30. When the connector is separated from the conduit, the double acting valve 36 simultaneously shuts both openings so that air is not ingested into the system. Likewise when the connector is fitted to the conduit, the double acting valve simultaneously opens both the connector 32 and the conduit 34 to allow fluid communication of the ink between the ink reservoir 30 and the print cartridge 14 without ingesting air into the system.

The conduit 34, Fig. 1 terminates in a particle filter 37 that collects any material that could clog the print cartridge 14 during operation. The filter is located on the high pressure side of the ink pressure regulator so that if any air is ingested in the reservoir 30, at the double acting valve 36 or in the conduit 34, the higher pressure will force the air to flow into the print cartridge and not become caught up in the filter and impede the ink flow.

The printer 12, Fig. 1, also includes a service station 40 that can draw a vacuum on the nozzles, not shown, on the print cartridge 14. The service station includes a deformable cup 42 that engages and seals against the nozzles. The cup is connected to a source of vacuum 44 by a valve 45. The service station operates by directing the print cartridge 14 over the cup 42 where a vacuum in drawn on the nozzles and the ink is sucked through the nozzles and out of the print cartridge.

The print cartridge 14 of Fig. 1 is shown in two exploded views in Figs. 2 and 3. The print cartridge includes a top plate 47 that is formed from two contiguous, over-lapping flat panels 50, 50'. The panels form an interior hollow passage 54 for the ink within the top plate. This passage receives an intake tube 48, terminates at an orifice 49, Fig. 5, and distributes ink into the print cartridge. The upper panel 50 of the top plate contains a small vent 53 that communicates with the atmosphere. The lower panel 50' contains a circular opening 51 of substantially larger diameter. Sandwiched and sealed between the panels 50, 50' is a diaphragm 52 that forms a fluid tight seal across the circular opening 51, Fig 5. The peripheral margin of the diaphragm 52 is thereby sealed against both air and ink. The diaphragm can be fabricated from either thin polyethylene plastic or polyvinyldene fluoride so that the diaphragm is impervious to both air and ink. The diaphragm is deformable and flexible and may be either resilient or not. When a pressure difference is developed across the surface of the diaphragm , the diaphragm expands into the print cartridge as illustrated in Figs. 4 -6. The upper side of the diaphragm is continuously exposed to atmospheric pressure through the vent 53.

Referring to Figs. 2 and 5, reference numeral 60 generally indicates a pressure regulator that supports the diaphragm 52 and regulates the pressure of ink supplied into the print head 14. The pressure regulator includes a lever 62 that rotates about an axle 64 that is supported from two supports 66. The supports are mounted on the underside of the lower panel 50' of the top plate 47. The lever also includes an integral arm 68 that contains a valve seat 70 for the ink orifice 49. The valve seat is a flattened, planar surface of room temperature vulcanizing silicone (RTV) and is counter sunk into the surface of the integral arm 68. The lever is aligned so that when the lever 62 is parallel with the plane of the top plate 47, the valve seat 70 is seated and ink orifice 49 is thereby shut as illustrated in Fig. 4.

The lever 62, Fig. 2 engages the diaphragm 52 with a piston 75 and an accumulator spring 74. The accumulator spring 74 is mounted in a circular depression 72 in the lever so that the spring does not move off of the lever 62. The piston is attached to the spring 74 and is held in place by a peripheral, concave engaging surface 76. Referring to Figs. 4, 5, and 6, the accumulator spring 74 is designed so that a differential pressure

across the diaphragm 52 can cause the diaphragm to flex and the piston 75 to move reciprocally up and down without moving the lever 62 and opening the ink inlet valve 49, 70. In Fig. 4 the diaphragm 52 is contracted slightly downward or is more concave in shape. In Fig. 6 the diaphragm is contracted slightly upward or is more planer in shape. The illustrated motion shows a portion of the wall of the ink containment moving and pushing any air bubbles that may be present toward the air collection area 98 of the print cartridge. This is an important aspect of air management within the print cartridge.

In Fig. 5 the ink valve 49, 70 opens when the piston 75 is forced sufficiently downward by the diaphragm to bottom out against the lever 62 and to mechanically cause its motion. The lever 62 is supported within the print cartridge 14 by a pressure setting spring 78. The pressure setting spring 78 is designed so that its force on the lever 62 is equal to the opening force or cracking force on the ink valve 49, 70. The pressure thereby developed is P0 or the cracking pressure of the regulator. The force of the pressure setting spring is set to be equal to the area of the diaphragm 52 that is uncovered by the opening 51, Fig. 2, multiplied by the pressure difference between atmospheric pressure and the pressure of the ink supplied to the print head 86, Fig. 5. Typically, this differential pressure is approximately minus three inches (-3") of water. The pressure setting spring 78 is also preloaded so that the force on the lever 62 is essentially constant over the travel of the lever. Such a constant spring force causes the motion of the lever to be large for any given change in the cracking pressure. In other words, a small change in pressure will cause a large movement in the lever. The net result is that when the valve seat 70 is moved off the valve nozzle 49 by a distance equal to approximately the radius of the nozzle 49, the valve will open to full flow condition.

Referring to Fig. 3, the print cartridge 14 further includes a housing 82 that receives the top plate 47 in a step 83 formed in the end of the side walls of the housing. The housing and the top plate together comprise the ink containment for the print head 86. The ink containment includes a main ink chamber 85 and a plenum 91 described below. The ink containment as well as the conduit 34, Fig. 1, and the ink reservoir 30 are fabricated from materials that are impervious to both air and ink such as poly sulphone, polyvinlydene fluoride, and liquid crystal polymers.

In the bottom wall of the housing 82 are a plurality of ink feed slots 84 that allow the ink to flow to the print head 86. The print head is a semiconductor substrate on to which are placed the firing chambers, the firing resistors, and the orifice plate in the conventional manner. The print head is mounted on a flexible conductor 87 by tab bounding and electrical signals to the firing resistors are established through the conductors 88, Figs. 1 and 3. When the print head is ejecting drops of ink, it is in effect pumping the ink out of the print cartridge and the pressure regulator 60 strives to develop and maintain a pressure P0. In the plenum, due to flow induced pressure drops, a lower pressure of P1 exists (slightly more negative that P0).

The print cartridge 14 is designed to entrap and to warehouse any air in the cartridge in the area 98. Air and air bubbles rise vertically to the top of the print cartridge to the predetermined area 98. Air is thus stored in an out of the way location so that air and air bubbles do not interfere with the flow of ink during printing.

Referring to Fig. 3, reference numeral 90 generally indicates a primming assembly for removing air from the interior of the print cartridge 14. The priming assembly includes four side walls 92 and a top wall 93 that form a plenum 91 around the print head 86. These walls also support the pressure setting spring 78 above the bottom wall of the housing 82. The top wall 93 includes two conduits that both communicate with the plenum 91. One conduit includes a flow orifice 94 and communicates between the main ink chamber 85 and the plenum 91. The other conduit is a snorkel 95 with an inlet 96 that connects the plenum 91 with an area 98 in the print cartridge where air is collected. The flow orifice 94 is sized so that during all printing operations the ink flows to the print head 86 through the orifice 94 and not through the snorkel 95. The orifice is sized so that when printing at maximum ink flow, the orifice has a pressure drop through it that is less than the height L of the snorkel 95. In one embodiment actually constructed the flow orifice 94 had a diameter of forty thousands of an inch (0.040") and the snorkel 95 had an inside diameter of eighty thousands of an inch (0.080").

The priming assembly 90, Fig. 7, also includes the service station 40 described above which can engage and seal the print head 86. The service station develops a differential pressure P2 - P0 across the plenum and draws ink out through the print head 86 at a much higher flow rate than during any printing operation. The flow orifice 94 is sized so that under this high ink flow condition, such a large pressure drop is developed across the flow orifice 94 that the ink and air in the top area 98 of the print cartridge are drawn down the snorkel 95 and out the print head 86 as illustrated in Fig. 7.

In operation, the ink reservoir 30, Fig. 1 and the print cartridge 14 are initially filled with ink and sealed. The ink conduit 34 may or may not be filled with ink. To begin, the ink reservoir 30 is connected to the ink conduit 34 by the double acting valve 36. When the printer 12, Fig. 1, commands the print cartridge 14 to commence ejecting drops 16, Fig.1, ink flows through the conduit 34 and any air in the conduit flows into the print cartridge and becomes trapped in the top area 98 of the housing. As illustrated in Fig. 4, at this point the print cartridge has a slight air bubble 98 in the top of the housing, the ink orifice 49 is shut by the lever 62, the diaphragm 52 is slightly concave, and any ink flow to the print head 86 is passing through the flow orifice 94.

As the print head 86, Fig. 5 continues to eject drops of ink on command from the printer, the pressure of the ink in the print cartridge 14 starts to drop. The differen-

tial pressure across the plenum 91 goes more negative. The diaphragm 52 becomes more concave due to differential pressure between atmospheric pressure in the vent 53 and the pressure in the main in chamber 85. This drop in pressure continues until the piston 75, Fig. 5, bottoms out against the lever 62 and then the diaphragm forces the piston to move the lever and to open the orifice 49 as illustrated in Fig. 5. This is rotational motion of the lever 62 around the axle 64, Fig. 5. The point at which the orifice 49 opens is the "cracking pressure" and is determined by the pressure setting spring 78. Ink then flows into the print cartridge 14, the pressure is in the print cartridge is restored, and any air is collected in the area 98. When the differential pressure across the diaphragm 52 decreases due to the inflow of the ink, the piston 75 allows the lever to shut the orifice 49 and the flow of ink into the print cartridge stops.

In the immediately above described process, the ink flow path through the print cartridge is first into the intake 48 of the top plate 47, Fig. 2, through the passage 54, Fig. 2, out the orifice 49, Fig. 5, into the main ink chamber 85, through the flow orifice 94, into the plenum 91, and out the print head 86.

If the temperature of the print cartridge goes up due, for example, to operation of the print head, this could cause either the pressure of the ink in the housing 82 to rise or the volume of ink to increase. As discussed above, a wall portion of the ink containment moves to accommodate this increase in temperature. The diaphragm 52 flexes upward as illustrated in Fig. 6 and becomes more planer to maintain the pressure within the housing constant. If there is a decrease in temperature, the diaphragm flexes downward and becomes more concave to maintain constant pressure. This is relative motion between the piston 75 and the lever 62 and is permitted by the accumulator spring 74. The lever 62 is remains stationary and is unaffected by such temperature excursions.

To remove air trapped in the top area 98 of the print cartridge 14, the print cartridge is purged using the service station 40. Referring to Figs. 7 and 8, a source 44 of vacuum is applied to the nozzles of the print head 86, a pressure P2 is developed in the plenum 91, and a very high ink flow rate is induced through the print cartridge. Any air in the print cartridge is drawn down the snorkel 95 as illustrated in Fig. 7 instead of through the flow orifice 94 because of the small size of the flow orifice and the large pressure drop across it. The volume of air drawn down the snorkel and out of the housing is replaced by a fluid volume of ink because the differential pressure in the housing drops and the orifice 49 opens as illustrated in Fig. 8. The result is to rapidly prime the print cartridge with ink and to remove the air from the system.

In the immediately above described process, the flow path of air and ink is from the predetermined air collection area 98, through the inlet 96, down the snorkel 95, into the plenum 91, out the print head 86, and into the service station 40.

It is contemplated that while there are a plurality of ways to remove air from the system using a source of vacuum, care should also be taken to minimize the amount of ink removed during the air removal process. Any excess ink so removed is ink unavailable for printing, and any ink so removed now needs itself to be warehoused. To minimize the removal of ink while removing air, a piston can be applied to the nozzles to draw down only a predetermined volume of the print cartridge. This would automatically limit the volume of ink and air removed from the print cartridge. As an alternative the source of vacuum could be timed with either a cam or clock to limit the application of vacuum to the nozzles.

It should be appreciated that there is a first conduit, the snorkel 95, Fig. 4, that communicates with the predetermined collection area 98 for air and a second conduit that contains the flow orifice 94 which communicates between the main ink chamber 85 and the plenum 91. Further, when a differential pressure P1 - P0 is developed across the plenum by the pressure regulator 60 and the print head 86, ink is directed through the ink flow path in the print cartridge including the second conduit. When a differential pressure P2 - P0 is developed across the plenum by the service station 40, Fig. 7, air from the collection area is removed from the print cartridge through the first conduit. Thus, by selectively altering the differential pressure across the plenum 91 between P1 - P0 and P2 - P0, the flow of fluid within the print cartridge is selectively shifted between the first and second conduits.

Referring to Fig. 9, reference numeral 14' generally indicates an alternative embodiment of the present invention. The conduit that communicates with the predetermined air collection area 98 is a conduit 102 that passes through a wall of the main ink chamber 85. This conduit contains a check valve 104 or "duck billed" valve that prevents the entry of air into the print cartridge. This conduit also is connectable to a source 44' of vacuum for drawing off the air from the air collection area.

Although specific embodiments of the invention have been described and illustrated, the invention is not be limited to the specific forms or arrangement of parts so described and illustrated herein. The invention is limited only by the claims.

Claims

1. Apparatus for removing air from an ink-jet print cartridge, comprising:

   a) a predetermined collection area for air within a print cartridge;

   b) a conduit having an inlet in fluid communication with said air collection area; and

   c) means, connectable to the conduit, for drawing off the air from the collection area through

the conduit so that air is removed from the print cartridge.

2. The apparatus of Claim 1 wherein the print cartridge further includes a print head and the air drawing means removes air from the print cartridge by drawing the air through the print head.

3. The apparatus of Claim 2 wherein the air drawing means is a service station connectable to the print head for drawing a vacuum thereon.

4. The apparatus of Claim 1 wherein the conduit passes through a wall of the print cartridge and further includes an outlet connectable to the air drawing means so that air is removed from the print cartridge through a wall thereof.

5. The apparatus of Claim 4 wherein the conduit contains a check valve for preventing the entry of air into the print cartridge through the conduit.

6. The apparatus of Claim 1 further including a wall member in the print cartridge that moves and thereby pushes air into the air collection area of the print cartridge.

7. In an ink-jet print cartridge having an ink flow path, apparatus for removing air from said flow path, comprising:

   a) a predetermined collection area for air within a print cartridge and in fluid communication with the ink flow path in the print cartridge;

   b) a first conduit for fluid flow with an inlet in fluid communication with said air collection area;

   c) a second conduit for fluid flow with an inlet in fluid communication with ink flow path;

   d) means, connectable to said first and second conduits, for selectively shifting the flow of fluid between the first and second conduits so that air from the collection area is removed from the print cartridge through the first conduit and ink is directed through the flow path in the print cartridge through the second conduit.

8. The apparatus of Claim 7 further including means, connectable to the first conduit, for drawing off air from the collection area and a print head in the print cartridge for pumping ink through the flow path.

9. In an ink-jet print cartridge having an ink flow path, apparatus for removing air from said flow path, comprising:

   a) a predetermined collection area for air within a print cartridge, said print cartridge having a pressure P0 therein;

   b) a vertical conduit of length L having an inlet in fluid communication with said air collection area and an outlet;

   c) a second conduit with a flow restricting orifice having an inlet in fluid communication with ink flow path and an outlet;

   d) a plenum in fluid communication with both the outlet of the vertical conduit and the outlet of the second conduit;

   e) a print head connected to the plenum for pumping ink through the flow path in the print cartridge, a differential pressure P1 - P0 is developed across the plenum for the print head; and

   f) means, connectable to the plenum, for developing a differential pressure P2 - P0 across the plenum so that when differential pressure P1 - P0 is developed across the plenum, ink flows through the second conduit with the flow restricting orifice and does not flow through the vertical conduit and when differential pressure P2 - P0 is developed across the plenum, air is drawn down the vertical conduit and is removed from the flow path.

10. The apparatus of Claim 9 wherein P1 - P0 is within a range of pressures of between about zero inches (0") of water and one quarter of an inch (1/4") of water and P2 - P0 is within a range of pressures of between about one half of an inch (1/2") of water and one hundred inches (100") of water.

11. The process of removing air from a print cartridge, comprising the steps of:

   a) collecting air within a print cartridge in a predetermined air collection area;

   b) locating a conduit in fluid communication with the predetermined air collection area;

   c) removing the air from the predetermined area; and

   d) replacing the air being removed with ink.

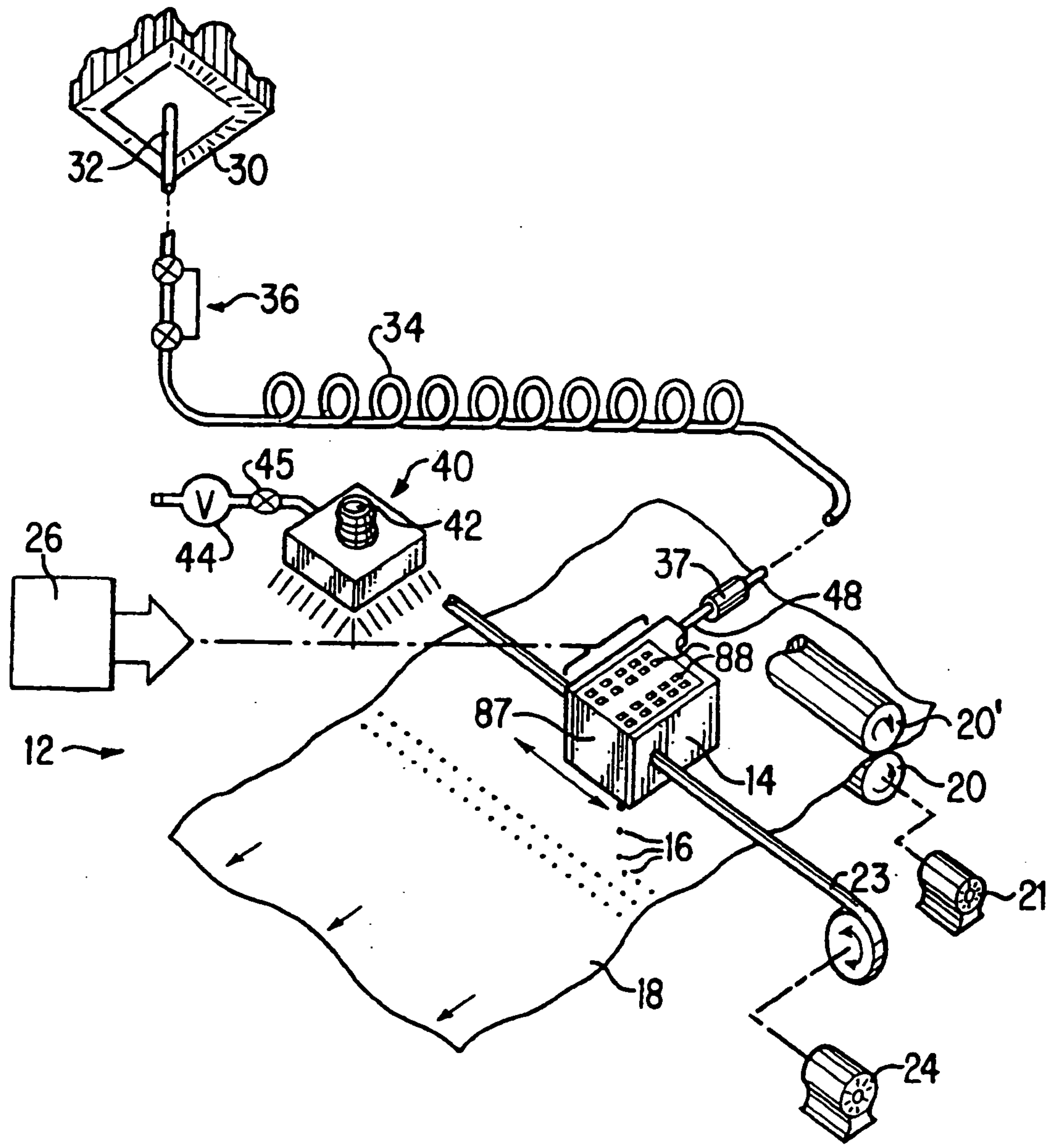


FIG. 1

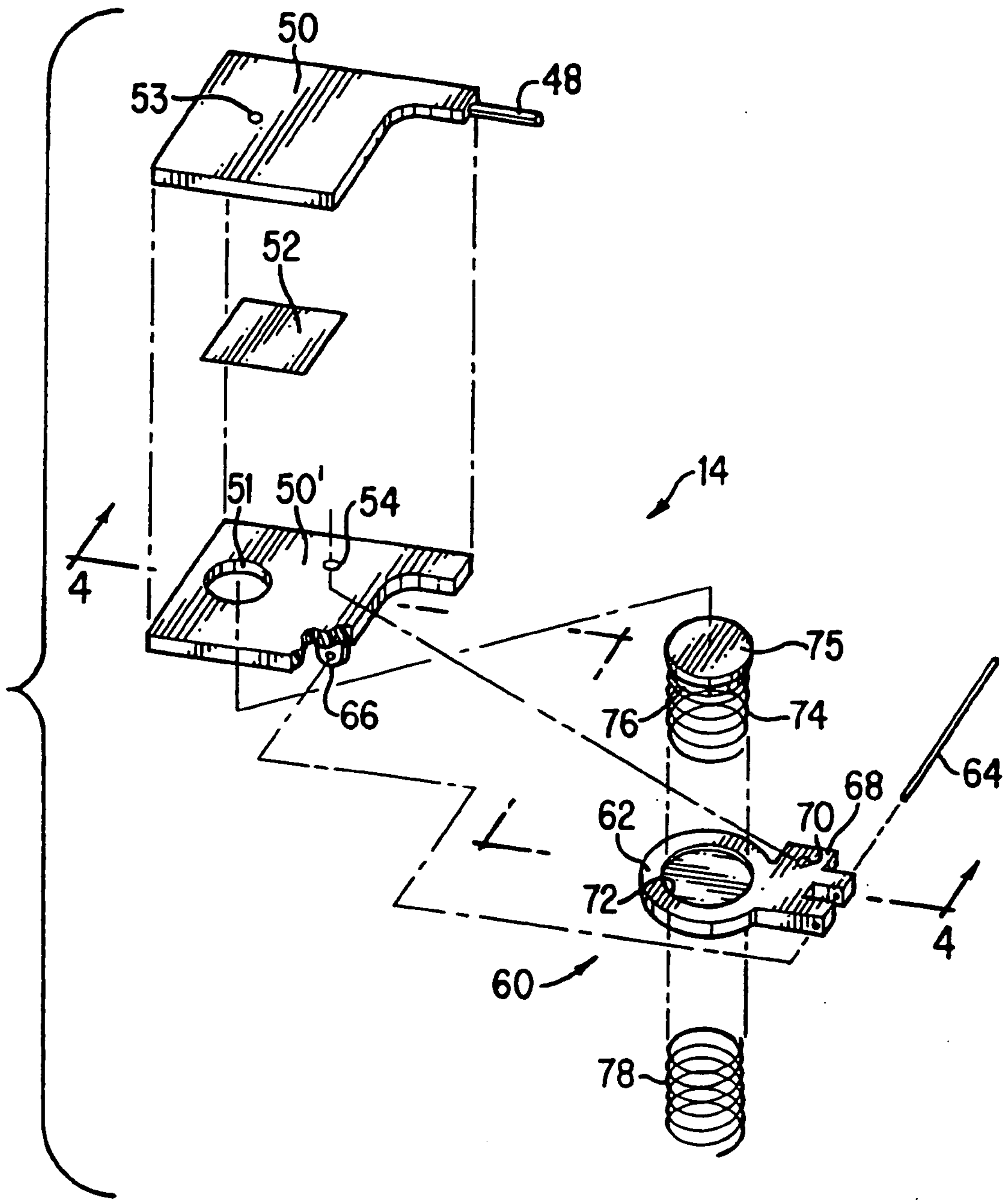


FIG. 2

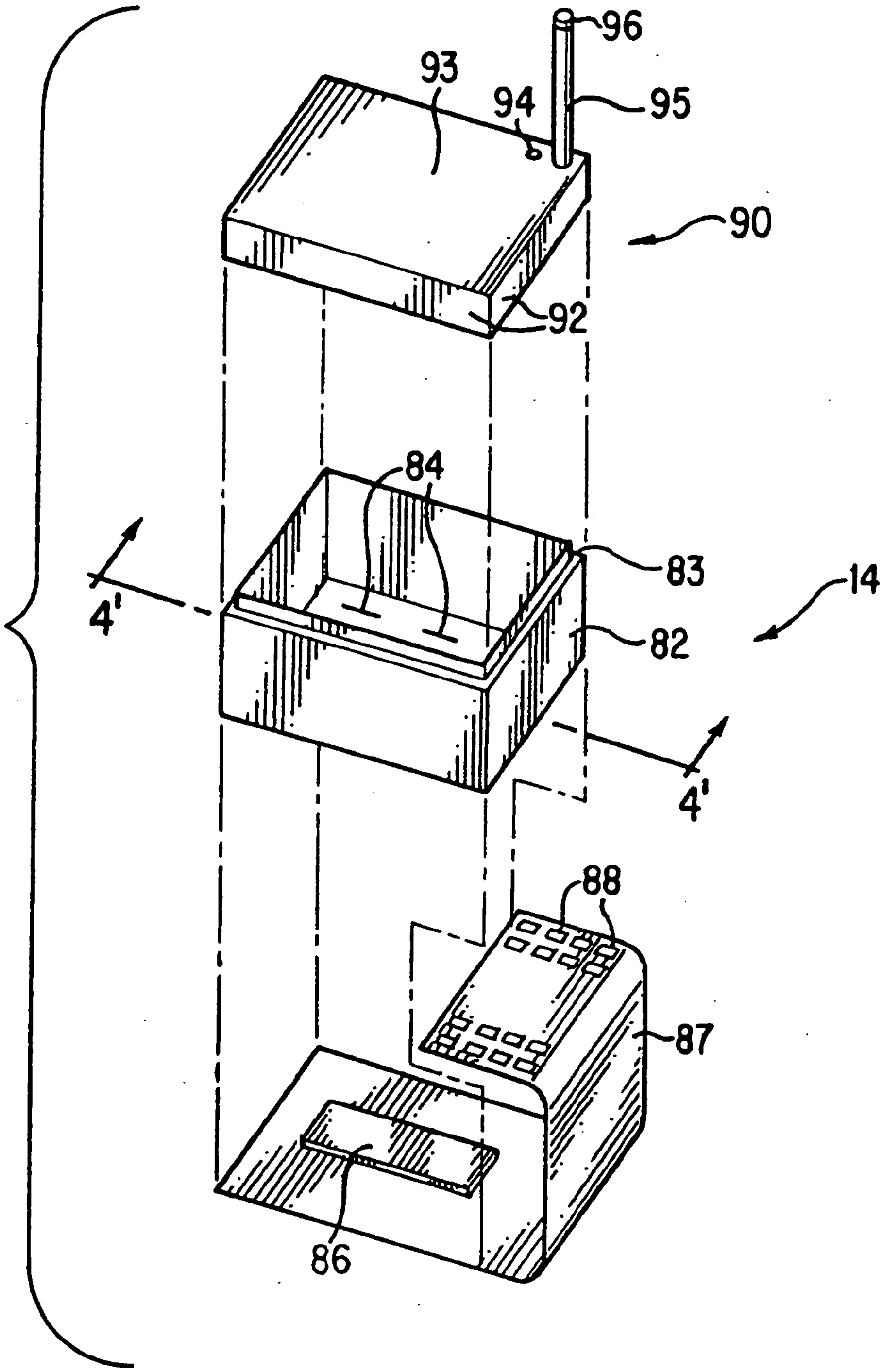


FIG. 3

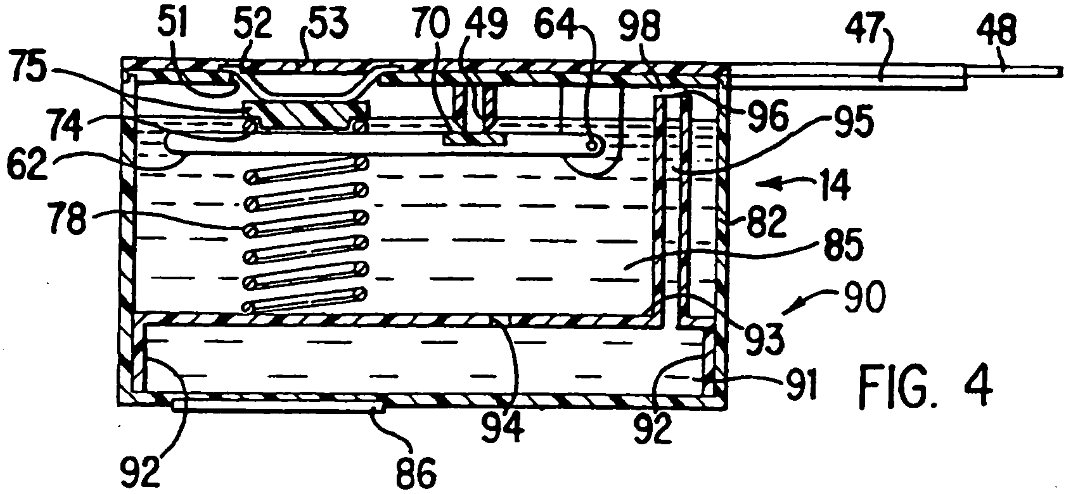
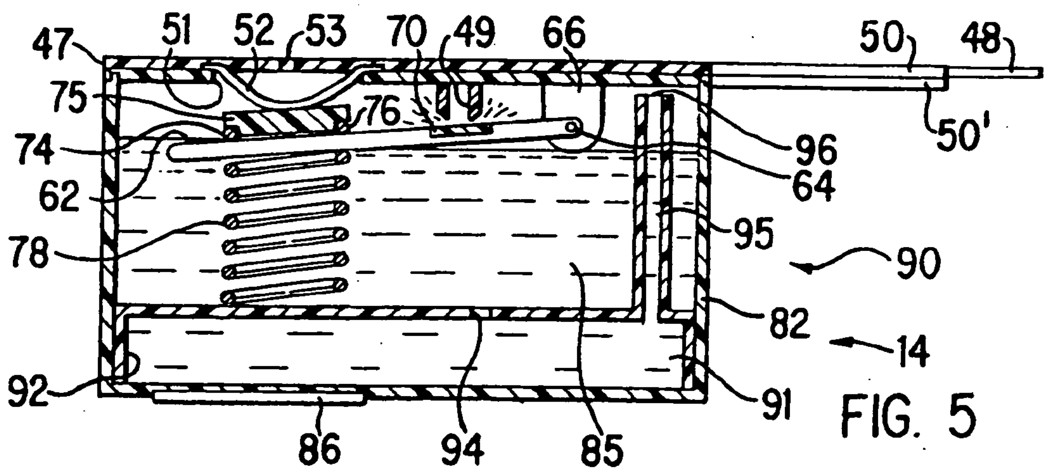


FIG. 4



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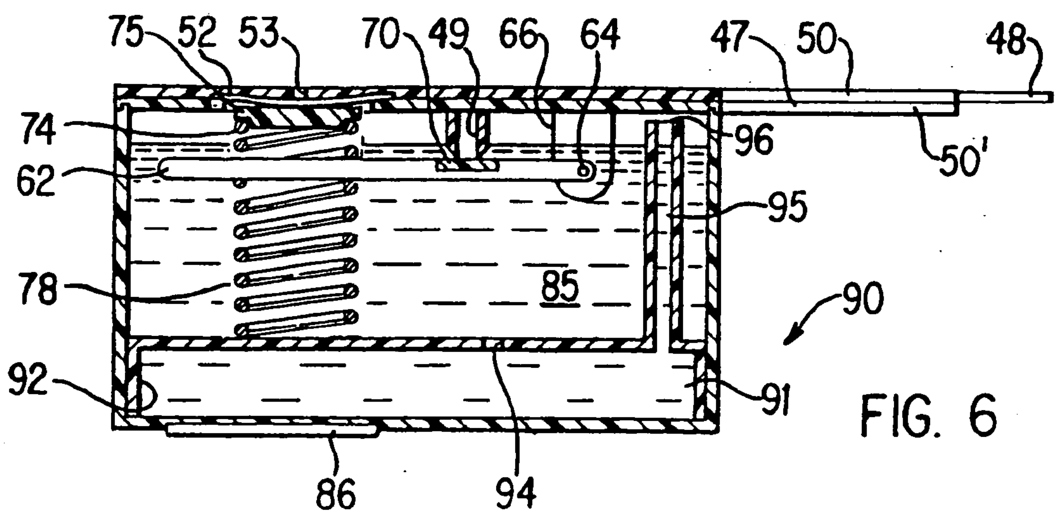

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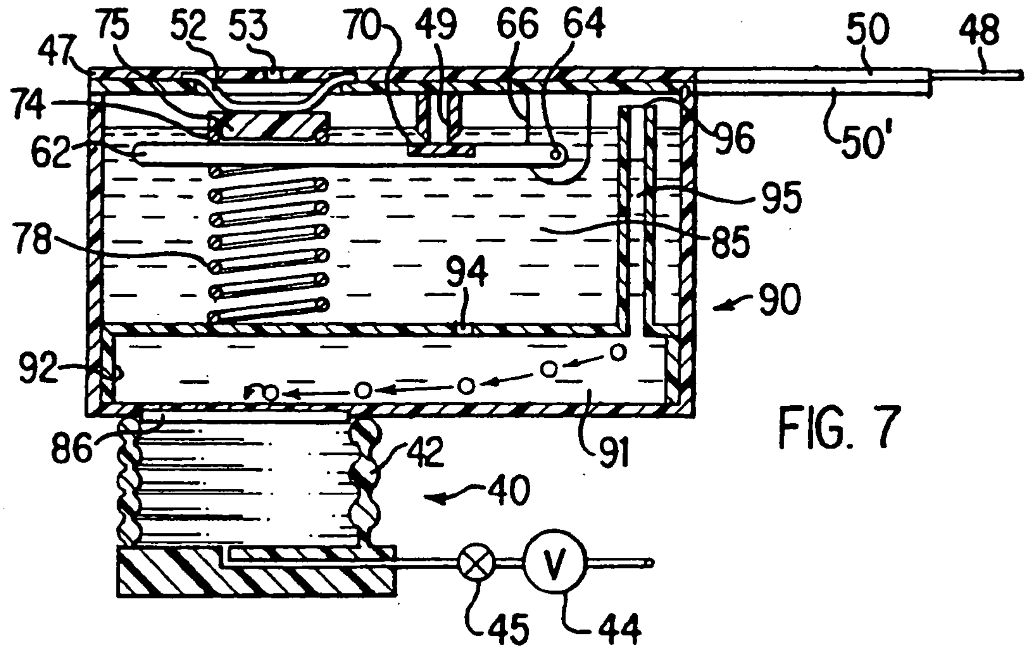
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FIG. 7

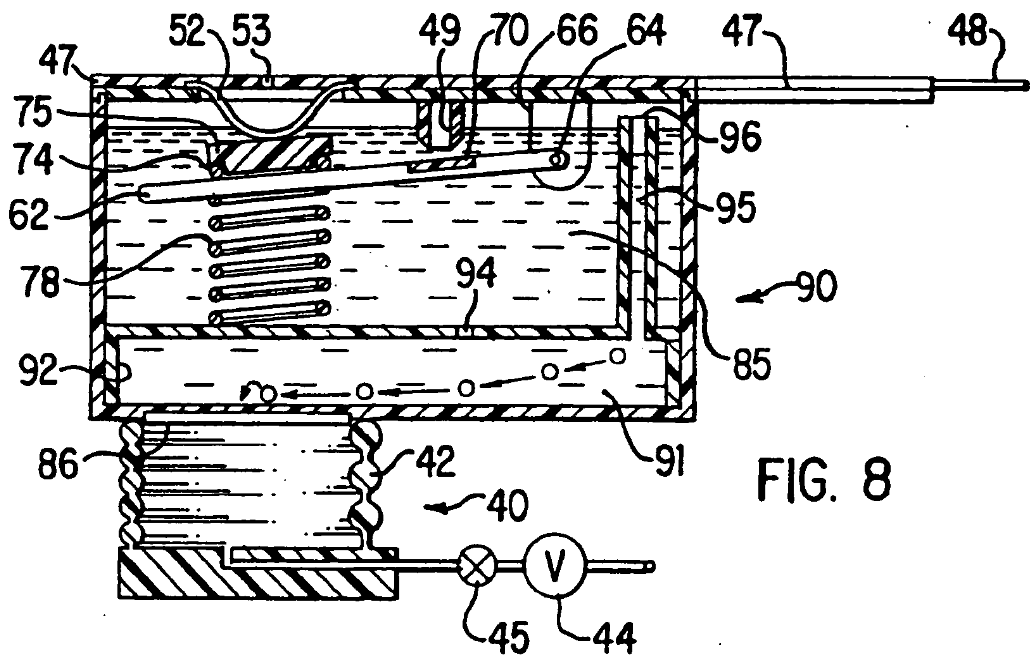
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FIG. 8

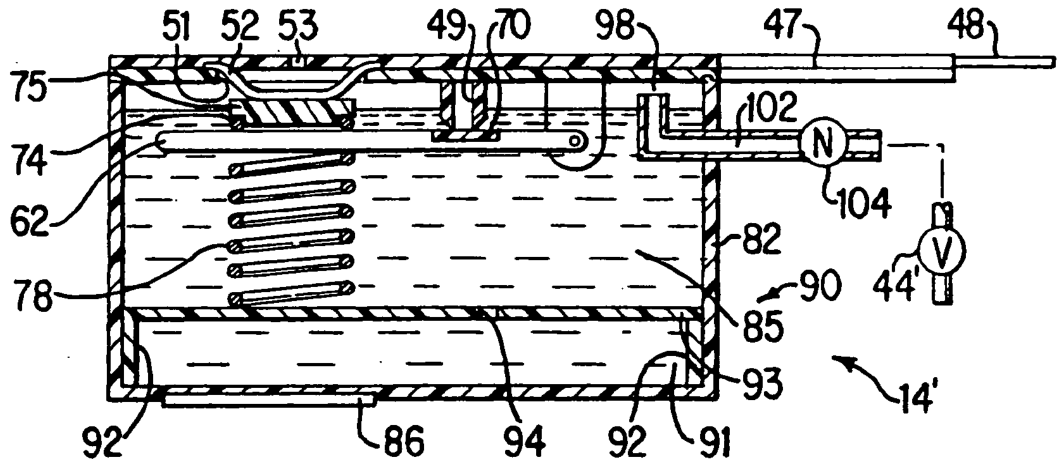
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FIG. 9